

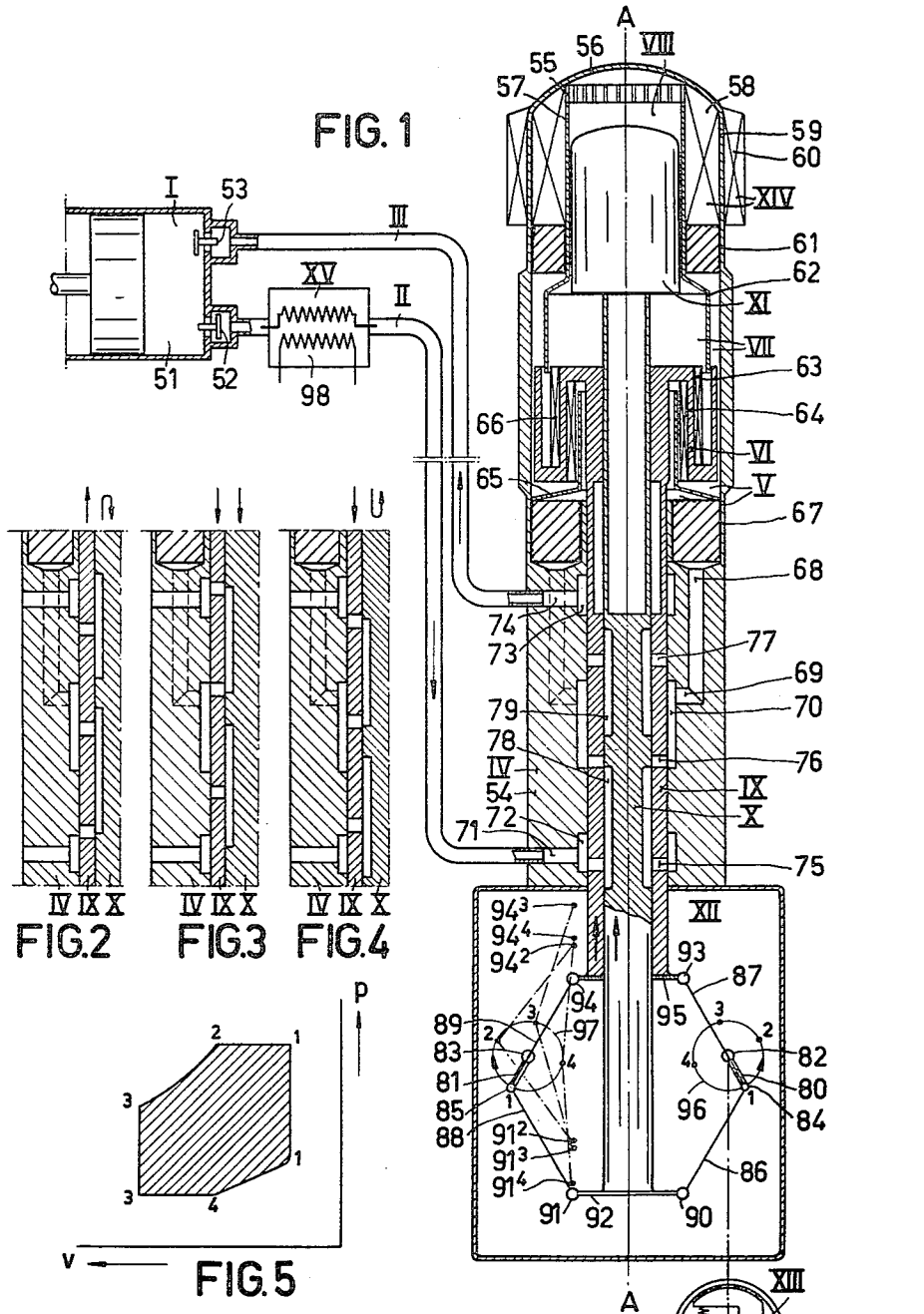
May 28, 1963

A. A. DROS

3,091,092

MULTI-STAGE REFRIGERATING ARRANGEMENT

Filed May 15, 1961



INVENTOR.
BY ALBERT A. DROS
Frank R. J. J. J.
AGENT

1

3,091,092

MULTI-STAGE REFRIGERATING ARRANGEMENT
Albert August Dros, Emmasingel, Eindhoven, Netherlands, assignor to North American Philips Company, Inc., New York, N.Y., a corporation of Delaware
Filed May 15, 1961, Ser. No. 109,901
Claims priority, application Netherlands June 1, 1960
6 Claims. (Cl. 62-6)

This invention relates to multi-stage refrigerating arrangements in which the working medium of the refrigerating machine for the higher temperature range at the area where it has, at least approximately, its lowest temperature is in heat-exchanging contact with the working medium of the refrigerating machine for the lower temperature range at the area where this medium has, at least approximately, its highest temperature.

Such a multi-stage refrigerating arrangement is characterized in that, for the lower temperature range, it comprises a cold-gas refrigerator with two piston-shaped bodies having different mean temperatures during operation of the arrangement and, for the adjoining higher temperature range, it comprises a refrigerating machine having a compressor and an expansion space which periodically communicates therewith and in which a piston is adapted to move. In this arrangement, the piston-like body with the higher mean temperature of the cold-gas refrigerator and the piston adapted to move in the expansion space of the refrigerating machine for the higher temperature range are formed by the two sides of the same double-acting piston-shaped body. In an arrangement according to the invention, the refrigerating machine for the higher temperature range is proportioned so that the amount of mechanical energy released upon expansion of the medium active therein is equal to, or greater than, the amount of mechanical energy required for driving the cold-gas refrigerator.

It is known to use multi-stage refrigerating arrangements for reaching very low temperatures. In certain cases, the area or the ambience where the required low temperature must be produced by such an arrangement will be difficult of access. The use of a multi-stage refrigerating arrangement in which the machine parts forming the various stages of the arrangement are rigidly coupled together then sometimes involves difficulty. It is advantageous to have at one's disposal such an arrangement in which it is possible to install part of the arrangement, for example with the aid of flexible conduits, at an arbitrary distance from another part of such an arrangement. However, it is then necessary for the driving mechanisms for the two parts of the arrangement to be separate in structural respect.

The multi-stage refrigerating arrangement according to the invention meets all these conditions. The presence of more than one stage in the arrangement renders it possible to make the arrangement produce cold at very low temperatures. The use of a cold-gas refrigerator for the lower temperature range makes it possible for a machine part having a minimum of moving parts and in which additional control members for the supply and discharge of working medium at very low temperatures are not required, to be arranged at the area or ambience to be refrigerated which may be difficult of access. By using a double-acting piston-shaped body in this machine part, the mechanical energy released upon expansion of the working medium active in the refrigerating machine for the higher temperature range can drive the cold-gas refrigerator in an extremely simple manner. Consequently, this drive is effected as it were pneumatically. Due to the heat-exchange between the media active in the cold-gas refrigerator and in the refrigerating ma-

2

chine it is ensured, as is usually the case in multi-stage refrigerating arrangements, that compression of the working medium in the cold-gas refrigerator can be effected at a temperature considerably lower than room temperature.

In one advantageous embodiment of the invention, the double-acting piston contains the heat-exchanger in which the working media of the cold-gas refrigerator and of the refrigerating machine are in heat-exchange contact with each other. This results in a compact assembly of the relative part of the arrangement and also a satisfactory beta-insulation can be provided.

In one embodiment of the multi-stage refrigerating arrangement according to the invention, the double-acting piston has two coaxial annular grooves which empty one into each end face of this piston, whilst the partition present in the piston between these grooves is provided with surface-enlarging means such as pins, fins or the like.

In another embodiment of the arrangement according to the invention, it is preferable that a stationary jacket-shaped body is arranged at each side of the double-acting piston, which fits with play into one of the co-axial annular grooves thereof. It is thus ensured that satisfactory heat-exchanging contact exists between each of the media and the wall of the heat-exchanger.

In another embodiment of the multi-stage refrigerating arrangement according to the invention, to ensure also for the expansion portion of the refrigerating machine for the higher temperature range that medium-dividing elements controlled by separate mechanisms are not required therein, the rods of the two piston-shaped bodies of the cold-gas refrigerator, positioned co-axially and adapted to move within each other, and also the housing surrounding these rods, are provided with channels and gates. It is thus ensured that the supply and discharge conduits to and from the expansion space of the refrigerating machine for the higher temperature range are opened and closed due to the relative movement of the said rods with respect to each other and the housing. The locally available moving parts of the cold-gas refrigerator are thus advantageously utilized for the periodic supply and discharge of working medium towards and from the relevant expansion space.

In another embodiment of the invention, the driving mechanism for the cold-gas refrigerator is a rhombic driving gear balanced at least substantially and preferably provided with a speed limiter.

The term "cold-gas refrigerator" in this specification is to be understood to mean a driven piston engine comprising a first space of variable volume which communicates freely with a second space, likewise of variable volume, which has a mean temperature higher than that of the first-mentioned space during operation of the machine. In this machine a regenerator is provided between the two spaces and a gaseous medium can flow forwards and backwards between the spaces through the regenerator, in order to transport heat from a lower temperature level to a higher temperature level.

In order that the invention may be readily carried into effect, it will now be described in detail, by way of example, with reference to the accompanying diagrammatic drawing, in which:

FIGURE 1 shows diagrammatically and in part section, one embodiment of a multi-stage refrigerating arrangement according to the invention;

FIGURES 2, 3 and 4 show, in different positions, parts of the two rods of the cold-gas refrigerator which connect the piston-shaped bodies present therein to the driving mechanism, and the housing surrounding the rods. From the corresponding part of FIGURE 1 and from FIGURES 2, 3 and 4 it can be deduced in what man-

ner the channels and gates provided in these parts for the supply and discharge of working medium of the refrigerating machine towards and from the expansion space thereof are opened and closed upon the relative movement of these rods and the housing.

FIGURE 5 shows the pressure-volume diagram of the expansion space of this machine.

With regard to the main structure of the multi-stage refrigerating arrangement shown in FIGURE 1, the following may be remarked:

The part of the arrangement indicated by I in FIGURE 1 comprises the compressor of the refrigerating machine for the higher temperature range. The part I communicates via a medium supply conduit II and a medium discharge conduit III with a machine part IV. These conduits may be flexible, if desired.

In the machine part IV, the following main parts can be distinguished: V indicates the expansion space of the refrigerating machine for the higher temperature range, which is located at one side of a double-acting piston VI. A space VII of variable volume with the higher temperature of the cold-gas refrigerator is located at the other side of the double-acting piston VI. The space of variable volume with the lower temperature of the cold-gas refrigerator is indicated by VIII. Two rods IX and X connect the double-acting piston VI and the other piston-shaped body XI of the cold-gas refrigerator to a driving mechanism XII which is provided with a speed limiter XIII. For a proper understanding it is mentioned that the illustrated multi-stage refrigerator arrangement produces cold at the area of the so-called freezer XIV at a temperature of, for example, -253°C . External fins 60 of the freezer thus extract heat from the ambience, such as a space to be refrigerated. The extracted heat is transferred via the gaseous medium active in the cold-gas refrigerator, such as helium, via the heat-exchanger present in the double-acting piston VI and a wall 64 which is at a temperature of, for example, -190°C . to the gaseous medium active in the other refrigerating machine, which may also be helium, but may alternatively be, for example, hydrogen. At the area of the so-called cooler XV, this medium gives off the absorbed heat, except for the losses, for example to water at a temperature of, for example, $+20^{\circ}\text{C}$.

During operation of the arrangement, one cycle is thus substantially performed in a compression space 51 of the compressor I and in the expansion space V present in the machine part IV. When a pressure valve 52 and a suction valve 53, provided on the compression cylinder, on the one hand, and the control members for the supply and discharge of working medium to and from the expansion space V, on the other hand, are opened and closed at the correct moments, the working medium is compressed in the space 51 which is at or above room temperature. Expansion of this working medium occurs in the space V at a temperature which is considerably lower, for example -200°C . The working medium of the cold-gas refrigerator, which is in heat-exchanging contact, via the walls of the double-acting piston VI, with the expanding medium of the refrigerating machine, thus assumes a temperature of, for example, -180°C . Consequently, the temperature of the freezer XIV of the cold-gas refrigerator is, for example, -253°C .

In addition to pre-cooling the medium active in the cold-gas refrigerator, the medium expanding in the refrigerating machine has the task to drive the cold-gas refrigerator. During the expansion stroke of the double-acting piston VI as a part of the refrigerating machine, this piston moves upwards thereby driving the hollow piston rod IX. With the aid of the said rod mechanism, which forms part of a so-called rhombic driving mechanism, the piston rod IX drives cranks 80 and 81 in directions indicated by arrows. The rods of the driving mechanism thus also drive the central piston rod X which in turn drives the piston-shaped body XI of the cold-gas

refrigerator. Due to the refrigerating machine being proportioned so that the amount of mechanical energy released therefrom at low temperature is equal to the amount of mechanical energy necessary for driving the cold-gas refrigerator, it is possible to design the machine part IV for driving the cold-gas refrigerator without taking further steps. Thus, the only connections necessary between the machine part I and the machine part IV are the medium supply and discharge conduits II and III, which may be flexible, if desired.

To prevent the machine part IV from assuming an unduly high speed if the load at the freezer XIV is insufficient, the rhombic driving mechanism XII is equipped with a speed limiter XIII, shown diagrammatically, which may be designed as a centrifugal brake.

With regard to the machine part IV, the following remarks as to the details may be made. This machine part comprises a housing 54 which contains all of the component parts associated with the cold-gas refrigerator. As previously mentioned, the space VIII of variable volume lies above the piston-shaped body XI which in operation constitutes the piston of this cycle with the lower temperature. The space VIII communicates via a circular groove 55, provided between the inner side of an end face 56 of the housing and a jacket-shaped body 57, with the interior 58 of the freezer XIV. Provided inside the freezer XIV are radially-extending fins which are in heat-exchanging contact via a wall portion 59 of the housing 54 with the external fins 60 of the freezer XIV. In the path of the medium active in the cold-gas refrigerator, the freezer is followed by a regenerator 61 which in turn empties into part of the space VII of variable volume with the higher temperature. The working medium then flows along the outer side of a jacket-shaped body 62 into a further part of the space VII, where it comes into contact with fins 63 provided on the outer side of the wall 64 of the double-acting piston VI, which serves as a heat-exchanger. The medium at last finds its way into the third part of the space VII of variable volume.

In the refrigerating machine for the higher temperature range, the working medium is thus present in the first place in the space V of the variable volume provided at the lower end of the double-acting piston VI. Each of these spaces also contains a jacket-shaped body 65 which enhances the heat-exchanging contact between this working medium and fins 66 provided on the inner side of the partition 64 in the double-acting piston VI. These spaces merge into a regenerator 67 which terminates in a plurality of channels 68 extending in an axial direction in the housing 54. The channels 68 are connected to inwardly-directed radial parts 69 which empty into a broad annular channel 70 provided in the inner wall of the housing 54.

The medium supply channel II, coming from the compressor I, is connected to a channel 71 provided radially in the housing 54 and merging into an annular channel 72. The latter is likewise recessed on the inner side of the housing 54. A third annular channel 73 in the housing 54 merges into a radial channel 74, which is connected to the medium discharge conduit III which leads back to the compressor I.

The hollow piston rod IX, which carries the double-acting piston VI, has three sets of radial bores 75, 76, and 77. The second piston rod X, enclosed by the hollow piston rod IX and hence connected to the piston-shaped body XI, has two broad annular channels 78 and 79 on its outer surface.

The driving mechanism XII of the machine, shown diagrammatically, comprises two cranks 80 and 81 which rotate in opposite sense at the same annular speed and are coupled together by gear wheels (not shown). These cranks are always located symmetrically with respect to the centre line A—A of the machine part IV. The centre lines of the associated crank shafts are indicated by 82 and 83 respectively. Two pairs of connecting rods 86, 87 and 88, 89 of equal length and oppositely directed are

5

connected to crank pins 84 and 85 respectively. The connecting rods 86 and 88 are coupled via pivots 90 and 91 to a yoke 92, rigidly connected to the inner piston rod X. The connecting rods 87 and 89 are connected via pivots 93 and 94 to a yoke 95, rigidly coupled to the hollow piston rod IX. When the cranks 80 and 81 are moved in the directions indicated by arrows, by the mechanical energy released upon expansion of the working medium of the refrigerating machine in the spaces V of variable volume, the two piston-shaped bodies of the cold-gas refrigerator acquire exactly such phase-shifted movements as are necessary for performing a cycle of the cold-gas refrigerator.

From FIGURES 1 to 4 it will be evident that the communication between the medium supply channel II and the space V of the refrigerating machine and also the communication between the space V and the medium discharge conduit III of this machine are periodically opened and closed by the co-action between the annular channels 72, 70 and 73, the bores 75, 76 and 77 and the annular channels 78 and 79.

Four different positions 1, 2, 3 and 4 of the crank 80 are indicated on the associated crank circle 96. These positions correspond to the relative positions of the two piston rods and the housing surrounding these rods, as shown in FIGURES 1 to 4. Similar positions 1 to 4 of the crank 81 are indicated on the associated circle 97, the locations of the pivots 91 and 94 corresponding to these positions also being shown. The locations of the pivot 91 are indicated by 91¹, 91², 91³ and 91⁴ respectively. Similarly, the locations of the pivot 94, corresponding to the positions 1 to 4 of the crank, are indicated by 94¹, 94², 94³ and 94⁴, respectively. It is thus possible to deduce from the locations of these pivots, the relative positions of the annular channels in the housing, those of the annular channels in the central piston rod X and the locations of the bores in the hollow piston rod IX.

The choice of the points 1 to 4 on the crank circles 96 and 97 is typical in so far that these points indicate the beginning of the inlet of working medium to the space V, the beginning of the outlet of working medium from this space and the beginning of the compression of the residual gas in this space. The arrangement may be derived from the locations of the annular channels and the bores in FIGURES 1 to 4 and from the pressure-volume diagram shown in FIGURE 5.

Since the rhombic driving mechanism, indicated by XII, may be fully balanced, if desired, the machine part IV has the property that it can be arranged at any desired area substantially free from vibration.

The supply conduit II includes the cooler 98 previously referred to. The total heat absorbed by the arrangement, including the heat absorbed by the freezer XIV, is extracted via the cooler 98 from a medium locally available, such as a liquid.

In the illustrated embodiment, a piston compressor is shown in the machine part I. As a matter of fact, this compressor may alternatively be of the rotary type.

What is claimed is:

1. A multi-stage refrigerating system in which each of two media perform a separated cycle, said media being alternately compressed and expanded whereby said media have different mean temperatures and the medium with the higher mean temperature at the area where it has at least substantially its lowest temperature being in heat-exchanging contact with the medium with the lower mean temperature at the area where this medium has substantially its highest temperature; comprising a cold gas refrigerator provided with a cylinder having a double acting piston and a displacer reciprocable therein for the cycle with the lower mean temperature, said piston and displacer having different mean temperatures during operation of said system, a refrigeration machine for the cycle with the higher mean temperature having compressor and an expansion space periodically communicating with said compressor, said cylinder defining said expansion

6

space, said expansion space being bordered on one side by a side of said double acting piston, another side of said double acting piston bordering the space of the cycle with the lower mean temperature where substantial compression occurs, and the cycle with the higher mean temperature constituting the driving means for said cold gas refrigerator.

2. A multi-stage refrigerating system as claimed in claim 1 wherein said double acting piston contains a heat exchanger in which the working medium of the cold gas refrigerator and the working medium of the refrigerating machine are in heat exchange contact with each other.

3. A multi-stage refrigerating system in which each of two media perform a separated cycle, said media being alternately compressed and expanded whereby said media have different mean temperatures and the medium with the higher mean temperature at the area where it has at least substantially its lowest temperature being in heat-exchanging contact with the medium with the lower mean temperature at the area where this medium has substantially its highest temperature; comprising a cold gas refrigerator provided with a cylinder having a double acting piston and displacer reciprocable therein for the cycle with the lower mean temperature, said piston and displacer having different mean temperatures during operation of said system, said double acting piston having two annular grooves, each opening into an end face of said piston, a partition in said piston between said grooves being provided with surface increasing means, a refrigeration machine for the cycle with the higher mean temperature having a compressor and an expansion space periodically communicating with said compressor, said cylinder defining said expansion space, said expansion space being bordered on one side by a side of said double acting piston, another side of said double acting piston bordering the space of the cycle with the lower mean temperature where substantial compression occurs, and the cycle with the higher mean temperature constituting the driving means for said cold gas refrigerator.

4. A multi-stage refrigerating system as claimed in claim 3 further comprising a stationary, jacket-shaped body being arranged at each side of said double acting piston and fits with play into one of said annular grooves.

5. A multi-stage refrigerating system comprising a cold gas refrigerator provided with a cylinder having a double acting piston and a displacer reciprocable therein for the cycle with the lower mean temperature, said piston and displacer having different mean temperatures during operation of said system, a refrigeration machine for the cycle with the higher mean temperature range having a compressor and an expansion space, a supply and a discharge conduit for periodically communicating said expansion space with said compressor, said cylinder defining said expansion space, said expansion space being bordered on one side by a side of said double acting piston, another side of said double acting piston bordering the space of the cycle with the lower mean temperature where substantial compression occurs, and the cycle with the higher mean temperature constituting the driving means for said cold gas refrigerator each having driving rods which are positioned co-axially one within the other and are adapted to reciprocate in said cylinder, a housing surrounding said rods, said rods and housing being provided with channels and gates whereby said supply and discharge conduits are opened and closed due to the relative movement of said rods relative to each other and said housing.

6. A multi-stage refrigerating system as claimed in claim 1 further comprising a substantially balanced rhombic driving arrangement provided with a speed limiter.

References Cited in the file of this patent

UNITED STATES PATENTS

2,558,481	Dros	June 26, 1951
2,951,334	Meijer	Sept. 6, 1960
2,982,088	Meijer	May 2, 1961